

EVALUATION OF SERVO RESPONSE DATA FOR TELESPECTROGRAPH SYSTEM

TE 1987

April 26, 1966

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FECKER PLANT

EVALUATION OF SERVO
RESPONSE DATA FOR
TELESPECTROGRAPH SYSTEM

TE 1987

April 26, 1966

NAS-1-4308



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1.0

INTRODUCTION

The purpose of this report is to present and analyze data taken on the telespectrograph built and installed at the Ascension Island tracking station by American Optical Company, Space-Defense Division. The data obtained here represents the system as it was established at the time of the project FIRE re-entry.

The system compensations, gains and transfer functions were adjusted during numerous fly-by exercises which were performed in a manner to simulate the tracking of the re-entry vehicle in the actual project FIRE test. These tests were performed with the tracking operator and American Optical personnel working together to determine the parameter settings at which this particular operator could best track a target requiring this particular set of mount velocity and acceleration requirements.

The results shown here are not optimum performance specifications and capabilities of the mount but instead are a selected performance established to render "best" performance



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taking into account the special projectile and trajectory along with the personal preferences of a particular tracking operator.

The flexible design and layout of this control system allows the rapid modification of gains and compensations to obtain optimum performance specifications for a wide range of tasks from the tracking of a star at Earth's rate (.004°/sec) up to the full operational capabilities of the mount (greater than 20°/sec).

The data taken and calculations performed show that improvements of an order of magnitude or better could be obtained in the performance specifications (rate smoothness, etc.) as obtained in the optimization procedure described above.

The following report is divided into three sections. The first presents a brief mathematical model of the system. The second describes the tests performed and gives the performance specifications as determined from these tests. The final section contains the data and calculations used to reduce this data to performance specifications.



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2.0 MATHEMATICAL MODEL

In the following section a simplified model of the system with emphasis on the velocity Servo loop will be developed.

- 2.1 The telespectrograph control system provides two basic modes of operation, a position mode and a velocity mode. The basic servo loop in both modes is a differential feedback (tachometer) velocity loop with the command signal applied to this loop being derived from a manually operated joy-stick in the velocity mode and from an error signal derived from axis mounted and remote command synchros in the position mode. A block diagram of the entire system is shown in Figure 2-1.
- 2.2 The velocity servo loop consists of three basic elements. The compensation amplifier which provides variable servo compensation, the power amplifier and hydraulic drive system in conjunction with the mount, and the tachometer feedback element.
- 2.3 Figure 2-2 shows the compensation amplifier schematic. The values of C_1 and C_2 are made variable by front panel switching to allow for rapid compensation adjustment.



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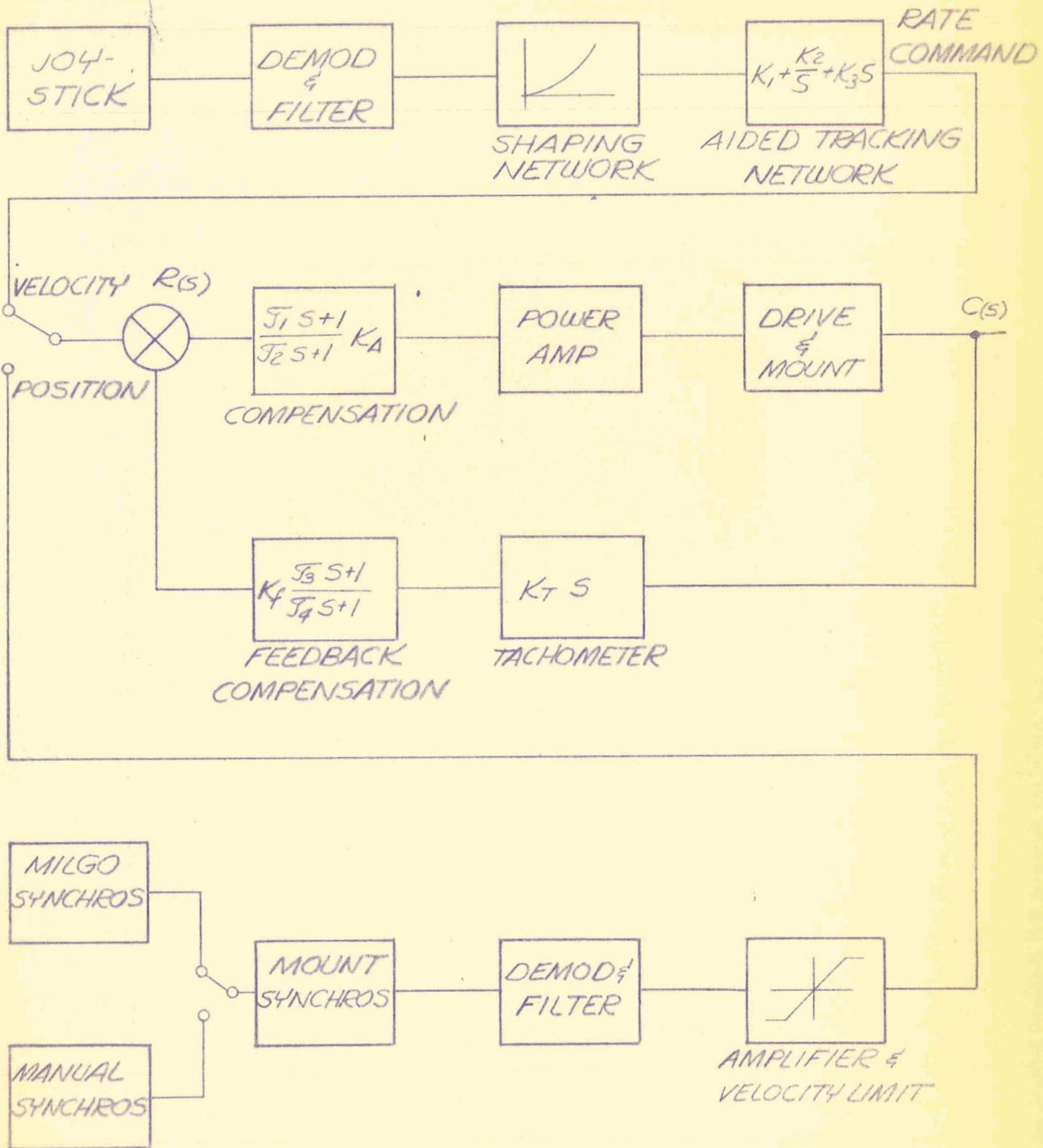


Figure 2-1
System Block Diagram



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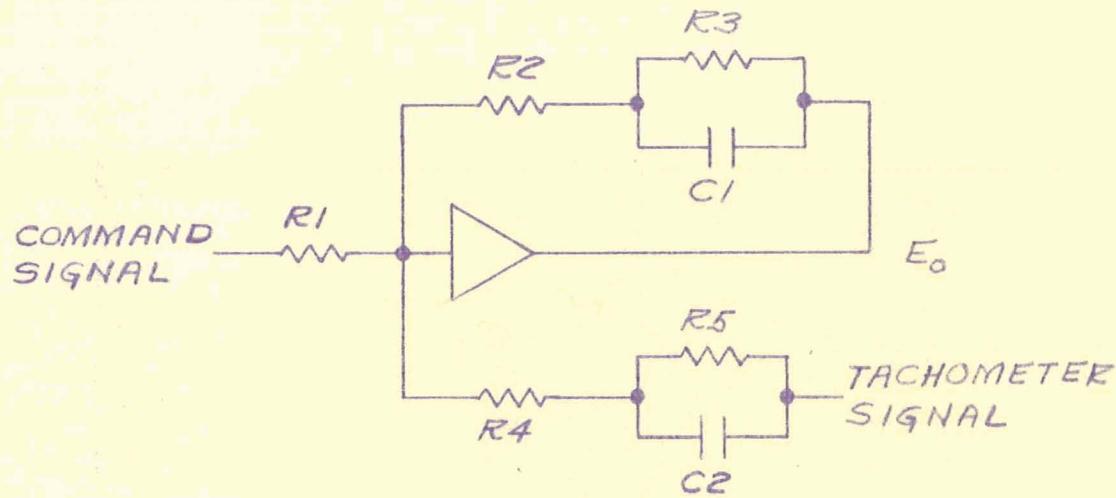


Figure 2-2
Compensation Amplifier

Referring to Figure 2-2 and making use of the relationship

$$E_o = -E_{in} \frac{Z_f}{Z_i}$$

where

E_o = Amplifier output

E_{in} = Amplifier input



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Z_f = Amplifier feedback impedance

Z_i = Amplifier input impedance for E_{in}

and Z_f and Z_i are defined as the short circuit impedances.

$$Z = \frac{V_{in}}{I_{sc}}$$

the following transfer functions relating the inputs to the outputs may be obtained.

$$\frac{E_o}{E_{tach}} = \frac{\frac{R_2 + R_3}{R_4 + R_5}}{\left(\frac{R_3 C_1 s + 1}{R_3 + R_2} \right) \left(\frac{R_4 R_5}{R_4 + R_5} C_2 s + 1 \right)}$$

$$\frac{E_o}{E_{command}} = \frac{\frac{R_2 + R_3}{R_1}}{\boxed{\frac{\frac{R_3 R_2}{R_2 + R_3} C_1 s + 1}{R_3 C_1 s + 1}}}$$

Or returning to the system block diagram Figure 2-1 the following transfer functions are applicable:

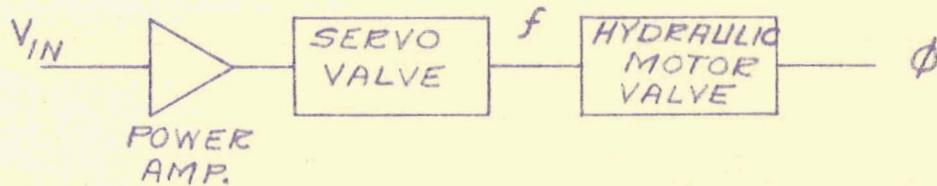
$$K_A \frac{\frac{\tau_1 s + 1}{\tau_2 s + 1}}{R_1} = \frac{\frac{R_2 + R_3}{R_1}}{\frac{R_2 R_3}{R_3 + R_2} C_1 s + 1}$$

$$K_f \frac{\frac{\tau_3 s + 1}{\tau_4 s + 1}}{R_4 + R_5} = \frac{\frac{R_1}{R_4 + R_5}}{\frac{R_4 R_5}{R_4 + R_5} C_2 s + 1}$$



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The mount drive system may be represented by the block diagram shown below:



The relationship between the servo valve output and the load angle ϕ is represented by

$$\frac{\phi(s)}{Y(s)} = \frac{k_m w_n^2}{s(s^2 + 2\xi_{wn}^2 + w_n^2)}$$

where

$$k_m = k_v \left(\frac{1}{1 + \alpha \frac{k_v}{k_p}} \right)$$

k_v = valve rotor velocity gradient, $\frac{\text{rad/sec}}{\text{in}}$

k_p = valve rotor torque gradient, $\frac{\text{in-lb}}{\text{in}}$

α = viscous drag of load & error, $\frac{\text{in-lb}}{\text{rad/sec}}$

$w_n^2 = \frac{Bd^2}{VJ} (1 + \alpha K_v / K_p)$ = resonant frequency squared



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B = Bulk modulus of fluid
 d = rotor displacement, in³/rad
 J = total inertia, in-lb-sec²
 V = effective entrained column, in³

$$\xi = \frac{K_v J w_n}{2 K_p} = (1 + \alpha \frac{V K_p}{K_v B d^2 J}) / (1 + \frac{K_v}{K_p})$$

The valve solenoid introduces time constants of the form

$$G(s) = \frac{K_x}{(T_e s + 1)(\frac{L}{R} s + 1)(s^2 + 2\xi_a w_s s + w_s^2)}$$

where

T_e = solenoid eddy current time constant

L = solenoid inductance

R = solenoid & amplifier resistance

ξ_a , w_a = mechanical damping and resonant frequency of
 solenoid, related to mass, damping, and spring
 constant of valve.

The power amplifier can be represented by a pure gain, K_a,
 in this case, since proper feedback techniques remove all
 poles and zero's well beyond those contributed by the solenoid
 and valve system.



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The total transfer function of the solenoid, valve, power amplifier and load can be represented by the product of the component transfer functions as below.

$$\frac{\Phi(s)}{V(s)} = \frac{K_L W_n^2 K_a K_x}{s(s^2 + 2\xi_1 w_n s + w_n^2)(T_e s + 1)(\frac{L}{R} s + 1)(s^2 + 2\xi_2 w_n s + w_s^2)}$$

In general, the poles contributed by T_e and W_s are located far out in the S plane and can be ignored. This results in a transfer function of the form

$$\frac{\Phi(s)}{V(s)} = \frac{K}{s(\frac{L}{R}s + 1)(s^2 + 2\xi_1 w_n s + w_n^2)}$$

2.3 If the transfer functions of the various components of the velocity loop are multiplied together the total open loop response is obtained. The result of this transform multiplication is:

$$\frac{V_{out}}{V_{in}} = \frac{K_a K_t (\frac{R_a R_3}{R_4 + R_5} C_1 s + 1) (R_5 C_2 s + 1)}{s(\frac{L}{R} s + 1)(s^2 + 2\xi_1 w_n s + w_n^2)(R_3 C_1 s + 1)(\frac{R_4 R_5}{R_4 + R_5} C_2 s + 1)}$$



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3.0

TESTS AND TEST RESULTS

In the following sections the various tests performed on the system are described and the system specifications as determined from these tests are presented. Critical points were monitored during all tests to insure against amplifier saturation during any test.

3.1

Open Loop Frequency Response Tests

The open loop frequency response data was obtained in two sections. The response of the power amplifier, servo valve, hydraulic motor and servo mount was obtained experimentally instrumenting the system as shown in Figure 3-1.

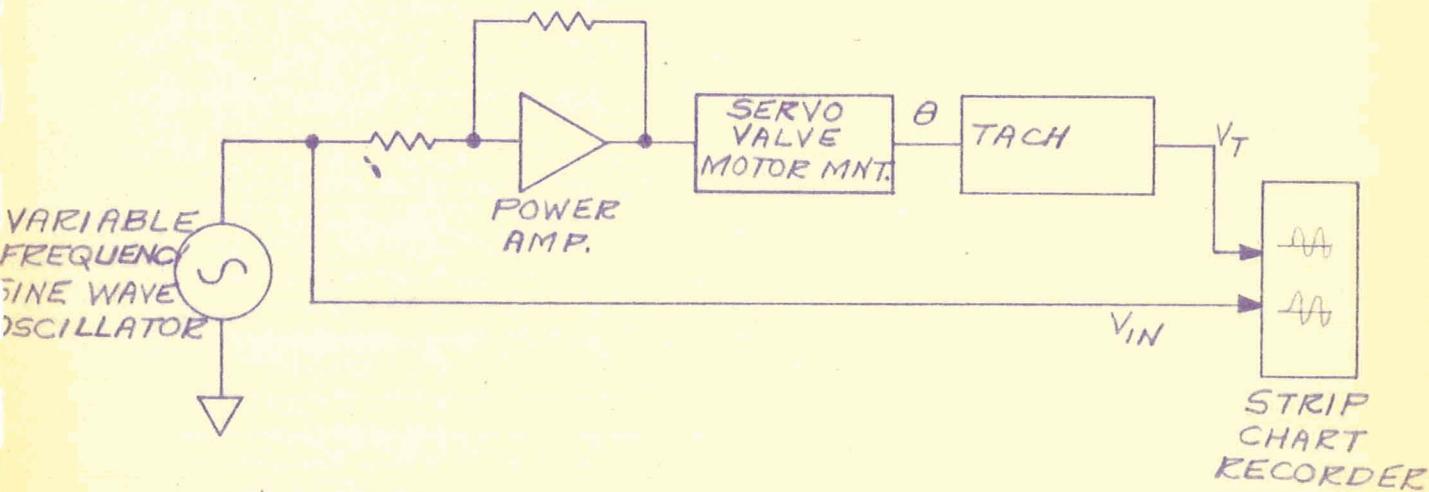


Figure 3-1
Open Loop Frequency Response
Test



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In order to obtain the complete open loop frequency response the transfer function of the compensation networks around the compensation amplifier were calculated and the amplifier response resulting from these networks was added to the log gain vs frequency and phase vs frequency Bode plots obtained from the experimental tests on the rest of the system. These calculations are shown in Section 4.1. From the resulting system open loop Bode plots, the open loop transfer function, phase margin, gain margin, and velocity error coefficients were obtained. The results are summarized below. Figures 3.1.2 and 3.1.3 show the Bode plots obtained from this test.

Azimuth Axis

Open loop transfer function:

$$KGH = \frac{1000 (.75 s + 1)}{(25 s + 1)(300 s + 1)(.01 s + 1)}$$

Phase Margin:

$$\phi_m = 115^\circ$$

Gain Margin:

$$G_m = 19 \text{ db}$$



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Velocity Error Coefficient:

$$Kv = 1000$$

Elevation Axis

Open loop transfer function

$$KGH = \frac{650 (.75 s + 1)}{(300 s + 1)(.03 s + 1)^2}$$

Phase Margin:

$$\phi_m = 95^\circ$$

Gain Margin:

$$Gm = 14 \text{ db}$$

Velocity Error Coefficient:

$$Kv = 650$$

3.2

Closed Loop Frequency Response

The closed loop frequency response of the velocity servo loop was obtained by applying the output of a variable frequency sine wave oscillator to the input of the loop and monitoring the tachometer output voltage for various input frequencies as shown in Figure 3.2



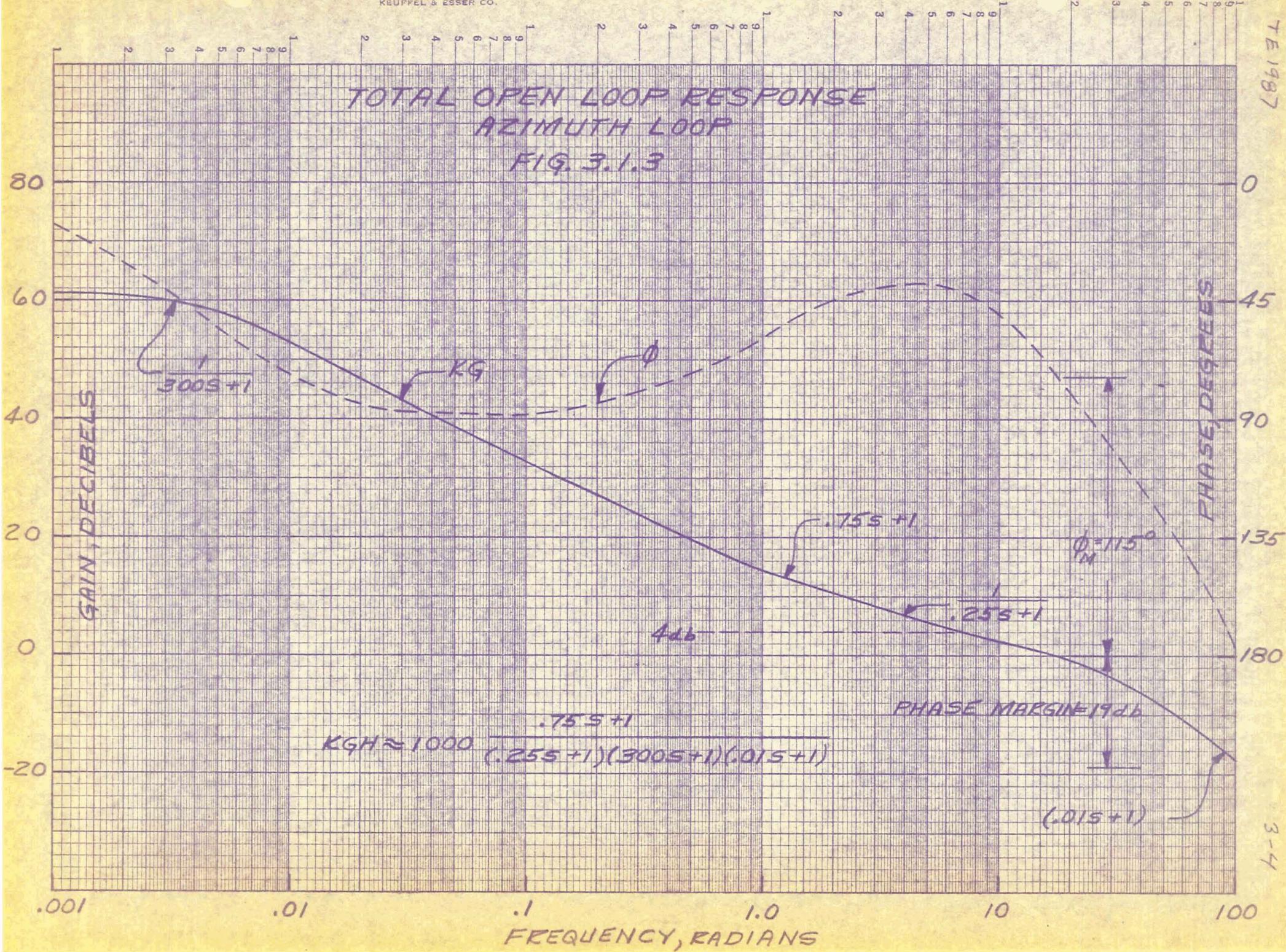
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TOTAL OPEN LOOP RESPONSE
AZIMUTH LOOP

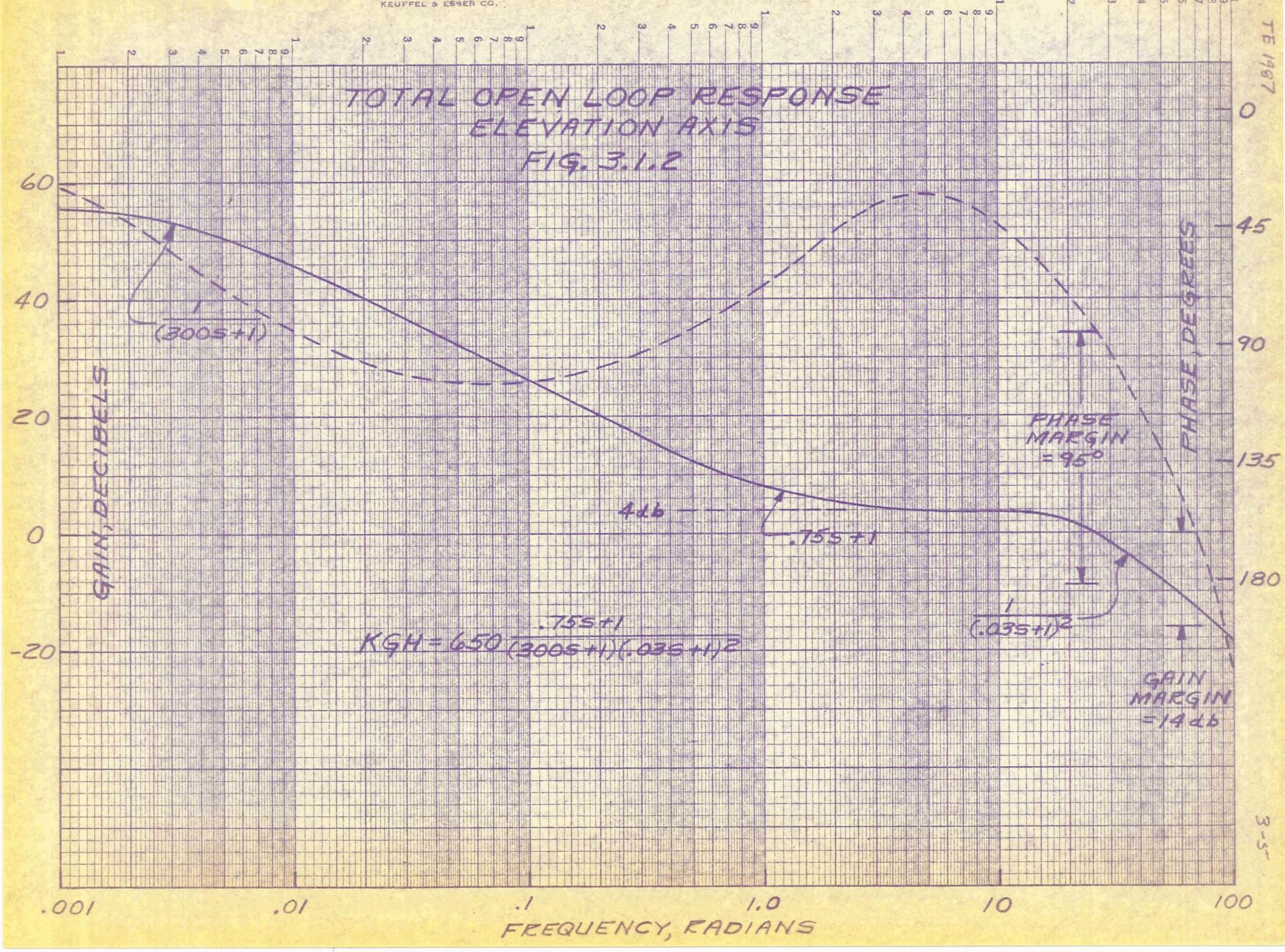
FIG. 3.1.3



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TOTAL OPEN LOOP RESPONSE ELEVATION AXIS

FIG. 3.1.2



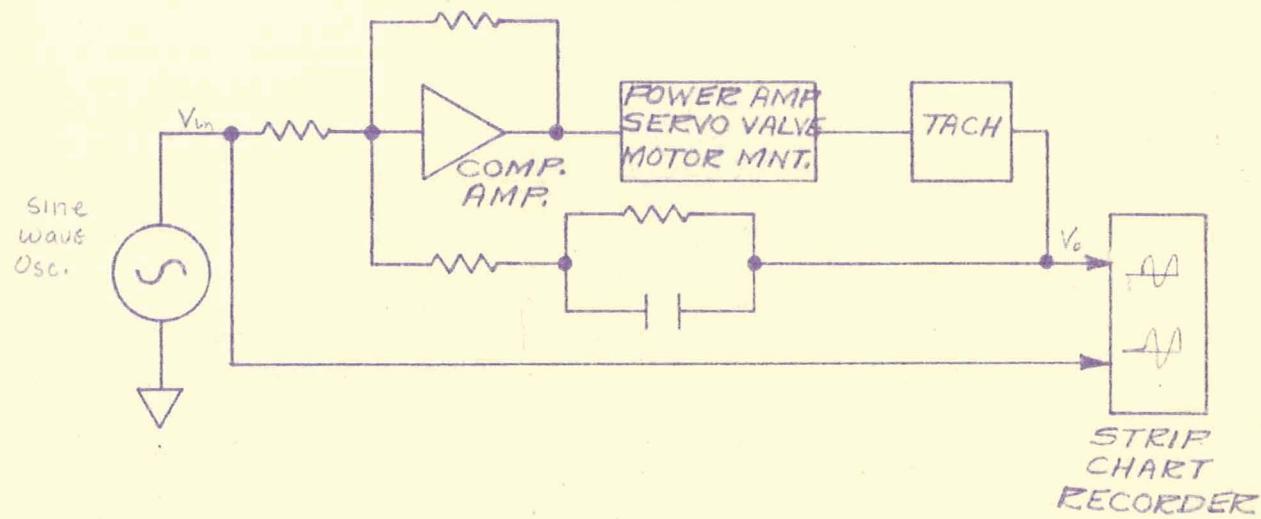


Figure 3.2.1
Closed Loop Frequency Response

The closed loop response as obtained from the open loop frequency response was also calculated from the relationship $C/R = KG/(1 + KG)$. The results of this calculation differ from the measured results due to the fact that unity feedback is assumed in the calculation while the measured



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system has a feedback equal to the gain of the compensation amplifier referred to its tach input signal, or referring to Figure 2.1 where the summing point has been placed at the input to the loop this difference is just K_f (since the time constants can be neglected). Both closed loop responses are shown in Figures 3.2.2 and 3.2.3. The bandwidths as obtained from the experimentally obtained closed loop data are as follows:

Azimuth Axis

$$Bw = 6.5 \text{ rad/sec}$$

Elevation Axis

$$BW = 4.5 \text{ rad/sec}$$

3.3 Open Loop Step Response Test

In order to obtain the maximum accelerations and velocity performance capabilities of the mount and drive system, step voltage inputs were applied to the input of the Power Amplifier with the velocity servo loop open. The tach output voltages were then recorded as larger and larger step inputs were applied until no further increase in acceleration and maximum velocity was noted when the amplitude of the step was increased.



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CLOSED LOOP RESPONSE
VELOCITY LOOP
AZIMUTH AXIS
FIG. 3.2.2.

CORRECTION FACTOR FOR
COMP AMP $k_p = -11 \text{ dB}$

GAIN (dB)

20
0
-10
-20

CALCULATED

MEASURED

10
100
FREQUENCY (RADIAN S)

1000

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5 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

GAIN (db)

20

10

0

-10

-20

-30

0.1

1.0

10

100

1000

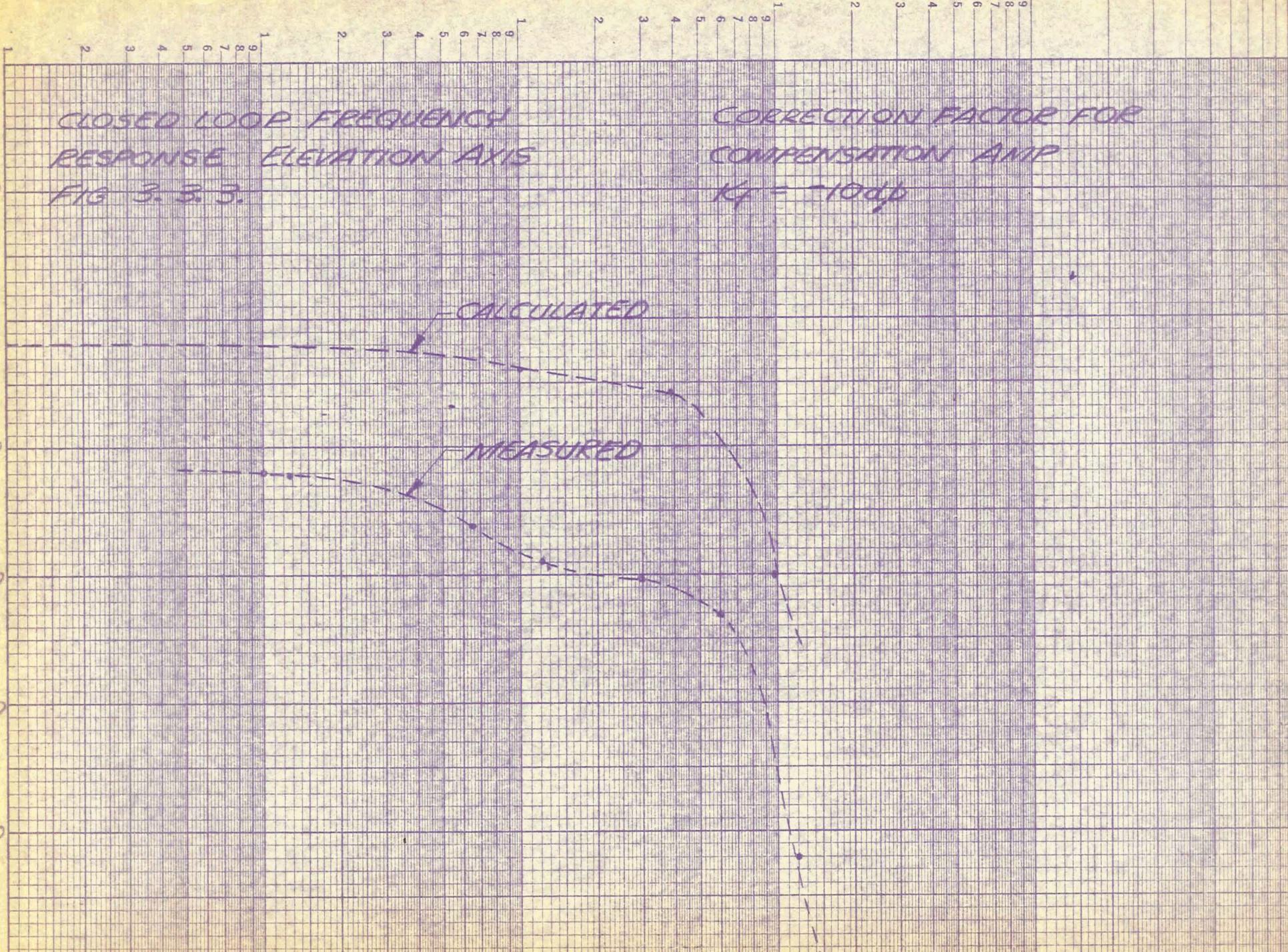
FREQUENCY (RADIAN S)

CLOSED LOOP FREQUENCY
RESPONSE ELEVATION AXIS
FIG 3.3.3.

CORRECTION FACTOR FOR
COMPENSATION AMP
 $K_f = -10 \text{ db}$

CALCULATED

MEASURED



The test set up is shown in Figure 3.3.1

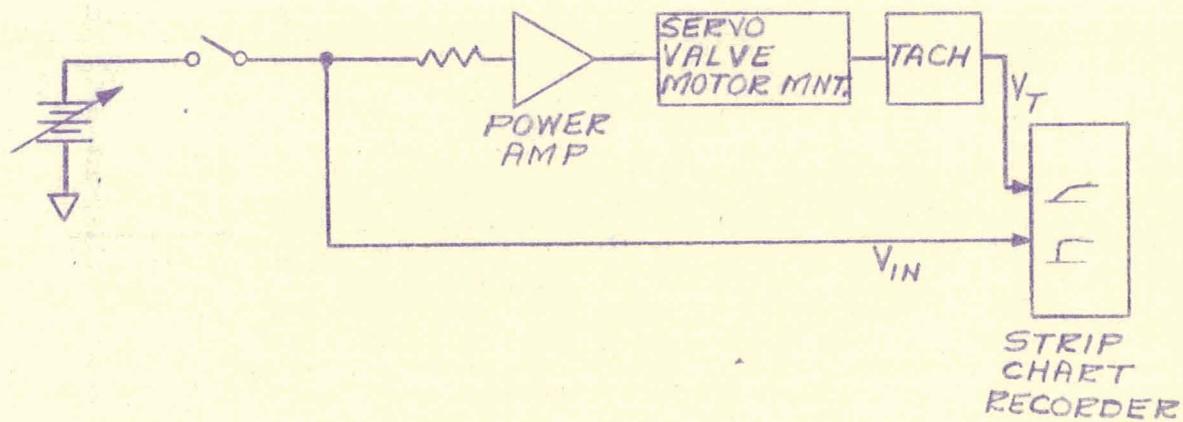


Figure 3.3.1
Open Loop Step Response

The maximum velocities and accelerations are tabulated below.

Aximuth Axis

$$\begin{aligned} \text{Maximum acceleration} &= 36^\circ/\text{sec}^2 \\ \text{Maximum velocity} &= 25^\circ/\text{sec} \end{aligned}$$



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Elevation Axis

Maximum acceleration = $98^{\circ}/\text{sec}^2$

Maximum velocity = $36^{\circ}/\text{sec}$

3.4

Closed Loop Step Response Tests

The purpose of the closed loop step response test was primarily to determine the minimum velocity at which the mount could be commanded to rotate. Other information which can be obtained from the data obtained in this test are rate smoothness at low rates and system Bandwidth. In this test a step input was applied to the closed velocity loop and the output was recorded on the strip chart recorder as shown in Figure 3.4.1.

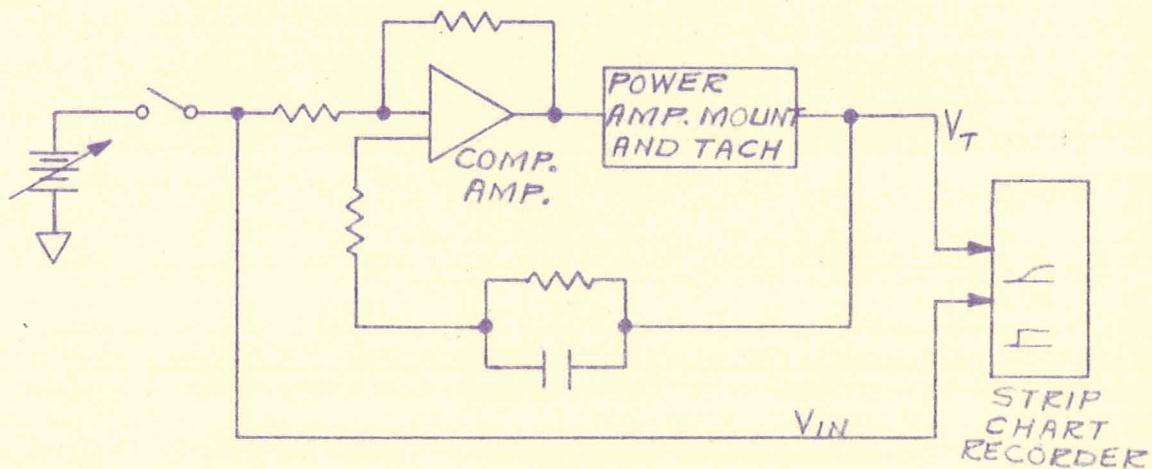


Figure 3.4.1
Closed Loop Step Response Test



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It should be emphasized here that the results of this test are by no means optimum for this system since the test data was obtained with the system "optimized" by a particular operators reaction to a fly-by with high velocities and accelerations with no attempt to optimize minimum response or velocity smoothness. From examination of the open loop frequency response it is evident that a considerable increase in the d-c gain of the system along with a corresponding change in the position of the compensation switches could be made which would retain the system Bandwidth, gain, margin, and phase margin. The increased d-c gain would then provide both increased Kv and decreased system response to load torque disturbances thus improving both the minimum response and velocity smoothness characteristics.

The results of this test showed the following system characteristics.

Azimuth Axis

Minimum Velocity Response $\approx .01^\circ/\text{sec}$

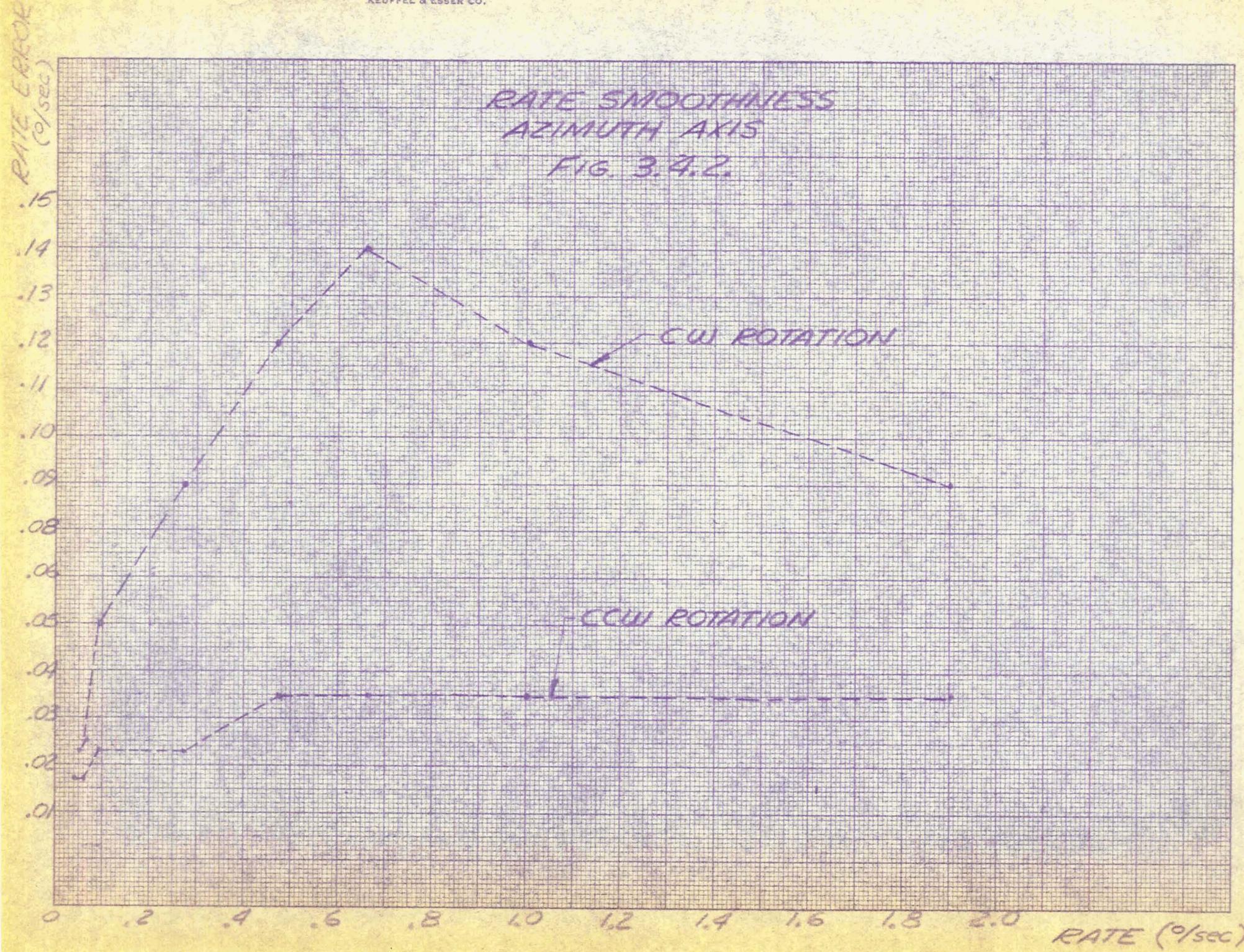
Bandwidth = 6.5 rad/sec



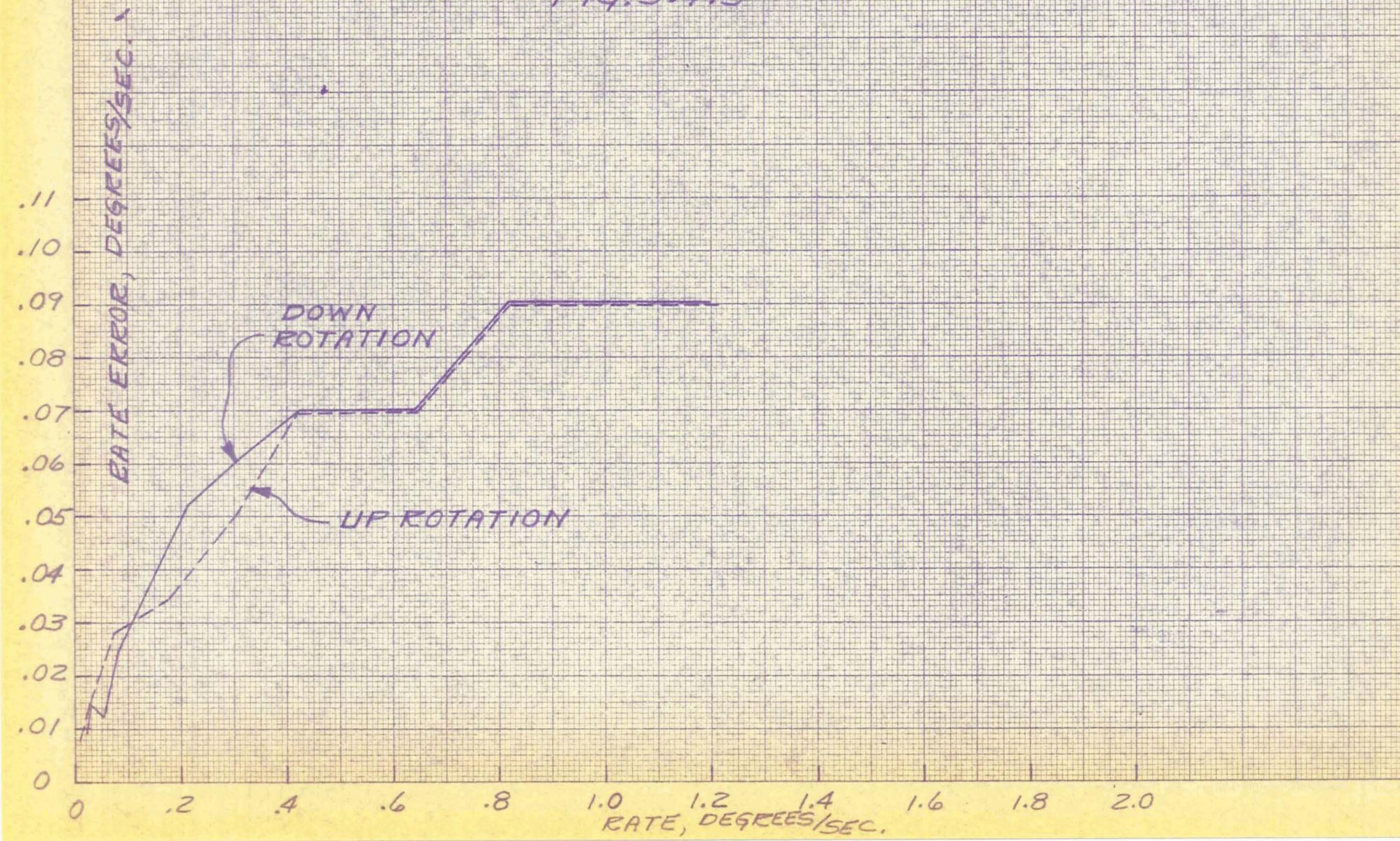
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RATE SMOOTHNESS
AZIMUTH AXIS

FIG. 3.4.2.



RATE SMOOTHNESS
ELEVATION AXIS
FIG. 3.4.3



Elevation Axis

Minimum Velocity Response $\approx .01^\circ/\text{sec}$

Bandwidth = 4.2 rad/sec

Curves plotting peak deviation from average rate error

versus rate at low rates are shown in Figures 3.4.2 and

3.4.3.

3.5 Joystick Response Test

In this test data was taken to obtain a plot of Velocity loop d-c input versus joy-stick deflection. This data was taken without the aided tracking circuit to obtain a correct curve of deflection versus d.c. output voltage. The results of this test are plotted in Figure 3.4.1.

The semi quadratic response shown in this curve was selected by the operator when given the choice of this response or a purely linear response. This type of curve allows higher resolution of rates in the low and intermediate range and allows rapid changes of velocity at the higher ranges. This response is achieved by means of a diode wave shaping circuit placed at the output of the demodulator filter.



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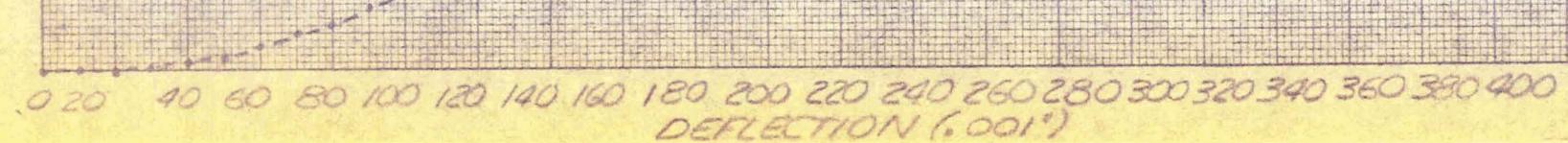
JOYSTICK INPUT VS OUTPUT VOLTS

FIGURE 3.4.1.

3

2

(VOLTS)



3.6

Position Transducer Response

In this test the steady-state d-c error applied to the velocity loop versus the position error as determined by the position command and feedback synchros was plotted. The results of these tests are shown in Figure 3.6.1 and 3.6.2.

With the saturation voltages shown in these curves the saturation or maximum velocity achieved during positioning can be obtained as:

Azimuth Axis

$$V_{\max} = 4.2^{\circ}/\text{sec}$$

Elevation Axis

$$V_{\max} = 12.5^{\circ}/\text{sec}$$

These are not absolute maximum values but represent the performance of the system with the particular set of gains and limiting networks in the system at the time of the test.



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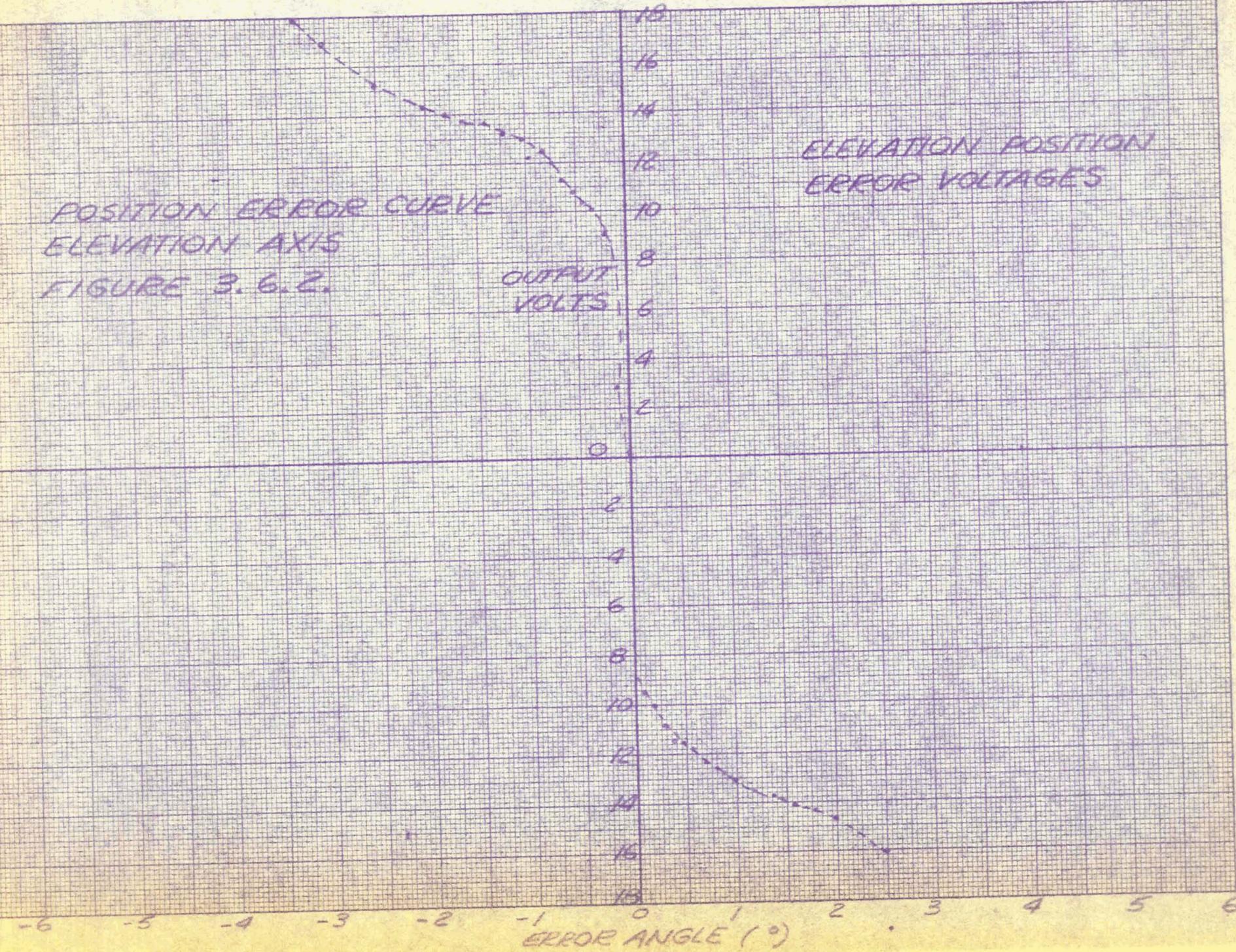
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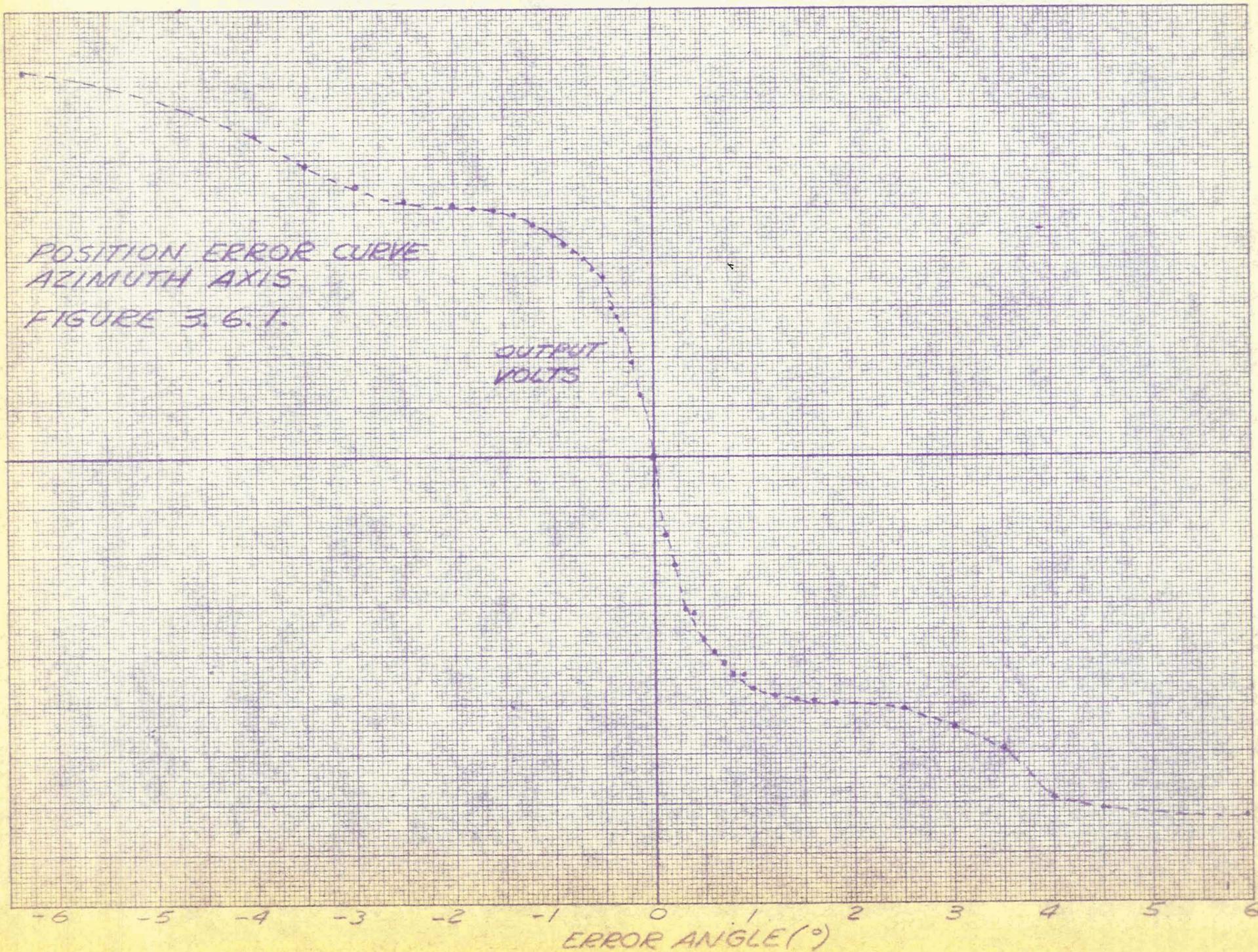
3-18

POSITION ERROR CURVE
ELEVATION AXIS
FIGURE 3.6.2.

OUTPUT
VOLTS

ELEVATION POSITION
ERROR VOLTAGES





4.0

Data and Calculations

In the following paragraphs the data and calculations used to obtain the results shown in section 3 are presented.

4.1

Open Loop Frequency Response

4.1.1

The open loop frequency response of the power amplifier, servo valve, hydraulic motor, mount, and tachometer were measured in this test. The data is shown in tables 4.1.1 and 4.1.2 and plotted in figures 4.1.1 and 4.1.2.



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Table 4.1.1

Frequency Response Open Loop

Azimuth Axis

Azimuth Tach Scale Factor =

$$190 \text{ V/rad/sec} = 3.32 \text{ V/Deg/sec}$$

$$= .302^\circ/\text{sec-volt}$$

Frequency Hz	ω rad/sec	Power Amp input volts	Tach Output volts	angle	(---) $G(s)$	(---) $G(s)$ db
0.097	.61	.44	57.5	40°	130.7	42.6
0.189	1.19	.40	49.0	70°	122.5	41.8
0.48	3.02	.40	38.0	11°	95.0	39.6
0.96	6.04	.38	26.0	34°	68.4	36.6
1.89	11.9	.38	21.5	59°	59.2	35.4
4.8	30.2	.42	12.5	98°	29.7	29.4
9.6	60.4	.41	5.8	139°	14.2	23.1
18.9	119.0	.32	1.6	180°	5.0	14.0



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Table 4.1.2

Frequency Response Open Loop

Elevation Axis

Elevation Tach Scale Factor = 163.7 Volts/radian/sec

$$= 2.86 \text{ volt/deg/sec}$$

$$= 35^\circ/\text{volt-sec}$$

frequency Hz	ω radians/sec	Power Amp input(volts)	Tach Output volts	Phase angle	G(S)	G_S (db)
.095	.59	.23	29.0V	13.8°	126.1	42
.188	1.18	.20	25.1V	8.45°	125.5	41.8
.378	2.37	.22	29.0	13.6°	131.8	42.4
.95	5.9	.215	28.0	22.0°	127.3	42.1
1.90	11.9	.020	24.5	44°	122.5	41.8
4.77	29.9	.215	15.1	106°	68.6	36.7
9.6	60.3	.20	5.8	166°	29.0	29.2
19.0	119.0	.18	1.0	220°	5.5	14.8



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0

45

90

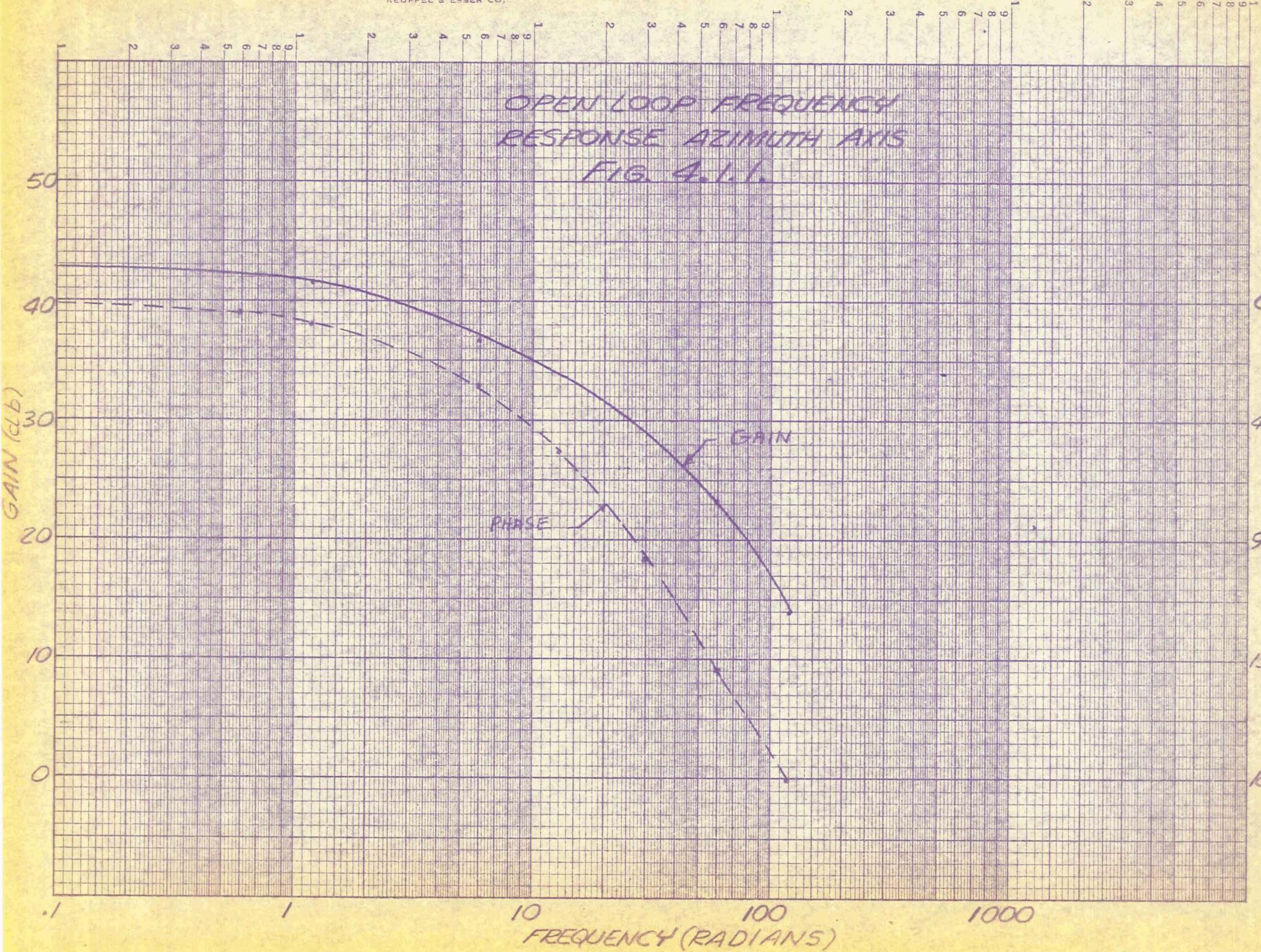
135

180

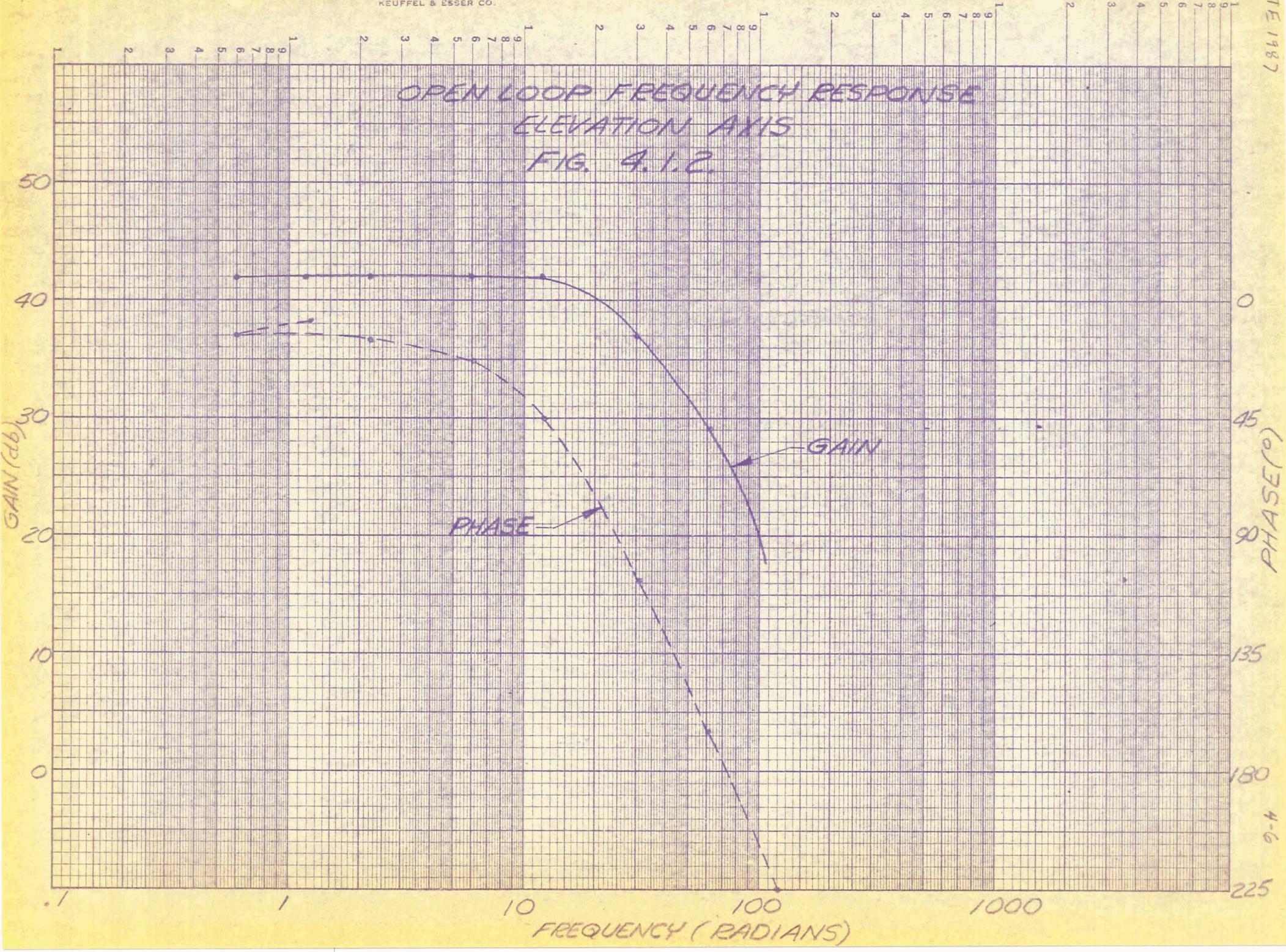
5-4

OPEN LOOP FREQUENCY
RESPONSE AZIMUTH AXIS

FIG. 4.1.1.

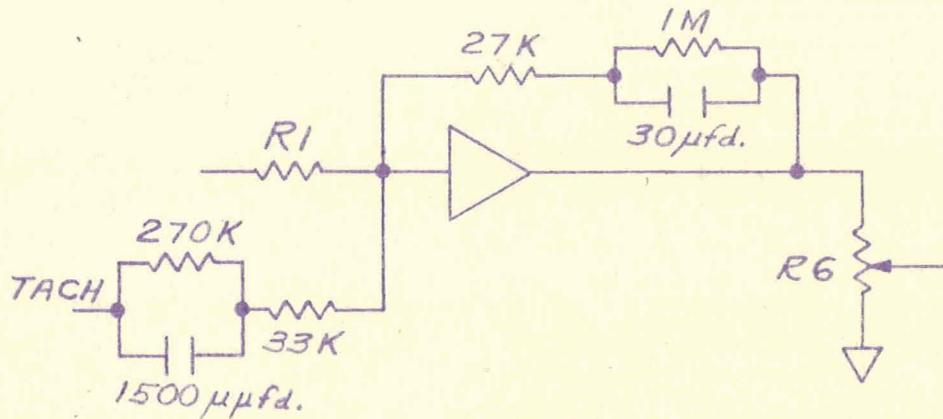


OPEN LOOP FREQUENCY RESPONSE
ELEVATION AXIS
FIG. 4.1.2.



4.1.2 Compensation Amplifier Response

The Compensation Amplifier is shown below



thus referring to figure 2.1

$$K_A \frac{\tau_1 s + 1}{\tau_2 s + 1} = \frac{10^7}{R_1} \frac{\frac{(10^7)(27 \times 10^3)}{10^7 + 27 \times 10^3} 30 \times 10^{-6}}{(10^7)(30)(10^{-6}) s + 1}$$

$$= \frac{10^7}{R_1} \frac{.75 s + 1}{300 s + 1}$$

$$K_f \frac{\tau_3 s + 1}{\tau_4 s + 1} = \frac{R_1}{3 \times 10^5} \frac{\frac{(27 \times 10^4)(1.5)(10^{-9})}{(2.7)10^9 3.3} s + 1}{3 \times 10^5}$$

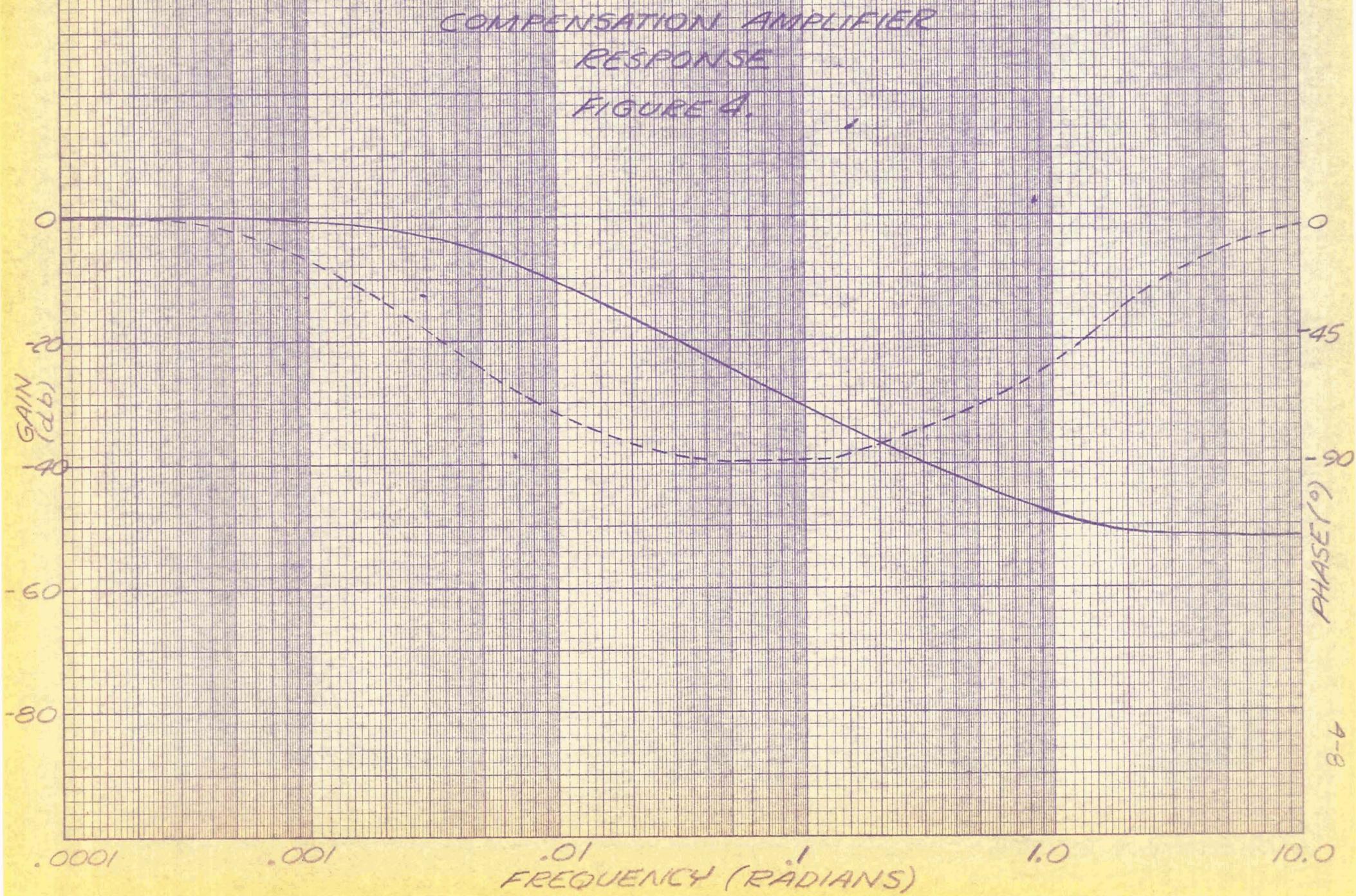
$$= \frac{R_1}{3 \times 10^5} \frac{4 \times 10^{-4} s + 1}{5.6 \times 10^{-5} s + 1}$$



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K+E
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Refering to figure 2.1 to get the total loop response we must add to the experimental open loop response a factor

$$\frac{10^2}{3} \frac{(.75 s + 1)(4 \times 10^{-4} s + 1)}{(300 s + 1)(5.6 \times 10^{-5} s + 1)}$$

The last pole and zero are located far to the left in the S plane and may be neglected and the absolute value of the gain is still unknown so from this we plot only an expression.

$$G_e(s) = \frac{.75 s + 1}{300 s + 1}$$

This is plotted in figure 4.1.3

The entire open loop response is now available except for an unknown gain factor. This must be found from the closed loop response data of para 4.2.1 Here we will set the point at which $C(s)/R(s) = 3 \text{ db}$ from the value of $C(0)R(0)$ as a fixed point and calculate the required gain for the total open loop response to give this response at that frequency using the relationship

$$\frac{C}{R} = \frac{KG}{1 + KG} = -3 \text{ db} \quad \text{i.e. } H = 1$$



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Note this will differ from measured closed loop response by a factor equal to K_f .

For the azimuth axis.

From the closed loop response

$$\frac{C}{R} = -3\text{db at } W = 6.5 \text{ rad sec.}$$

Then from the open loop response

$$KG = K \angle -40^\circ \text{ at } 6.5 \text{ rad/sec}$$

and substituting

$$\frac{1}{Y^2} \angle \theta = \frac{K \angle -40^\circ}{1 + K \angle -40^\circ} = \frac{K \angle -40^\circ}{1 + .77K - .64K}$$

setting magnitudes equal

$$\frac{1}{Y^2} = .7 = \frac{K}{\sqrt{1 + 1.54K + .59K^2 + .4K^2}}$$

solving

$$K^2 - 1.54K - 1 = 0$$

$$K = 1.69 \approx 4\text{db at } W = 6.5$$

thus by adding the calculated compensation amplifier response to the experimental mount and drive section data and setting the gain equal to 4db at 6.5 rad/sec the total open loop response is obtained and is shown



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in figure 3.1.2

Elevation Axis

from the closed loop response

$$\frac{C}{R} = 3 \text{db at } 4.5 \text{ rad/sec}$$

from the open loop response

$$KG = K \angle -33^\circ$$

and substituting as before

$$\frac{1}{\sqrt{2}} \angle \theta = .7 \angle \theta = \frac{K \angle -33^\circ}{1 + K \angle -33^\circ}$$

solving as before

$$K \approx 1.65 \approx 4 \text{ db}$$

Then adding the three portions of the open loop response

the total response is plotted in figure 3.1.3



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4.1.3 Error Coeficients

The KGH functions obtained from the total open loop response relate the output of the tachometer multiplied by K_f to an input voltage command. Thus in order to retain its normal definition the velocity error coefficient is defined as

$$K_V = \lim_{s \rightarrow 0} KGH$$

For the azimuth axis then

$$K_V = \lim_{s \rightarrow 0} \frac{1000 (.75 s + 1)}{(.25s + 1)(300 s + 1)(.01 s + 1)} = 1000$$

For the elevation axis

$$K_V = \lim_{s \rightarrow 0} \frac{650 .75s + 1}{(300 s + 1)(.03 s + 1)^2} = 650$$

4.2

Closed Loop Frequency Response

The data obtained in the closed loop frequency response test is shown in Tables 4.2.1 and 4.2.2. The curves plotted from this data as well as the closed loop curves obtained from the open loop data are shown in Figures 3.2.2 and 3.2.3.



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Closed Loop Frequency Response

Azimuth Axis

$$\frac{C}{R} = \frac{\text{Tachometer Volts}}{\text{Input Volts}}$$

frequency Hz	ω (rad/sec)	tachometer output (volts)	power amp input (volts)	$\frac{C(s)}{R}$	$\frac{C}{R}$ (db)
.2	1.25	42V	12V	3.5	10.9
.4	2.5	42V	12V	3.5	10.9
1	6.3	29V	11.5V	2.5	8.0
2	12.5	20.5V	11.7V	1.9	5.6
2	12.5	21V	11.7V	1.9	5.6
5	31.0	9.5	10.8	.88	-1.2
10	62.8	4.4	9.8	.45	-7.0
20	126.	1.4	6.5	.22	-13.1

TABLE 4.2.1



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Closed Loop Frequency Response

Elevation Axis

$$\frac{C}{R} (S) = \frac{\text{Tachometer Volts}}{\text{Input Volts}}$$

frequency (Hz)	ω (rad/sec)	tachometer output (volts)	input (volts)	C/R	C/R (db)
.2	1.25	9.7	12.2	3.6	11.1
.4	2.5	11V	15.3	3.2	10.0
1	6.3	7V	14.5	2.1	6.4
2	12.5	5.2	15.3	1.6	4.1
5	31.0	4.7	14.7	1.4	3.1
10	62.8	4.0	15.1	1.2	1.6
20	126	.58	10.1	.27	-11.4

TABLE 4.2.2



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4.3

Open Loop Step Response

The data for this test is shown in tables 4.3.1 and 4.3.2. Maximum velocity calculations were made using the relationship

$$\omega_{\max} = \frac{\text{Tach voltage (max)}}{\text{Tach scale factor (volts/}^{\circ}\text{/sec)}}$$

Maximum accelerations were obtained from the relationship

$$a_{\max} = \text{Tach Scale Factor (}^{\circ}\text{/volt-sec)} \times \text{Max Slope}(\frac{\text{volts}}{\text{sec}})$$



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Open Loop Step Function Response

Azimuth Axis

Step Input Volts	Maximum Tachometer output (volts)	Max Slope volts/sec	Max Vel. °/sec	Max Acc. °/sec ²
.1	12.6	24	3.8	6.8
.2	28.1	86	8.5	26
.5	58.5	123	17.6	37
5.4	81.0	120	24.4	36
6.0	80.0	120	24.3	36

TABLE 4.3.1



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Open Loop Step Function Response

Elevation Axis

Step Input (Volts)	Maximum Tachometer Output(Volts)	Max Slope Volts/sec	Max Velocity °/sec	Max Accel. °/sec ²
.1	12.5	122	4.3	36.8
.2	28	230	9.8	69.3
.4	58	262	20	78.4
3.6	99	325	36	98
5.0	98	325	36	98

TABLE 4.3.2



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4.4

Closed Loop Step Response Tests

The results of the closed loop time domain tests are shown in tables 4.2.1 and 4.4.2. The final test in each axis was run at a very rapid chart speed to allow determination of the system Bandwidth from the relationship

$$Bw \approx 0.4/T_r$$

where

T_r = Rise Time (time required for system to go from 10 % to 90 % of final value)

The smoothness data was obtained by dividing the steady state average rate into one-half of the peak to peak steady state ripple in order to obtain average to peak information.



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Closed Loop Step Response Tests

Azimuth Axis

Direction of Rotation	Input (Volts)	Average S.S. Tach output (Volts)	Average S.S. rate °/sec	Average ripple (Volts p-p)	Rate °/sec	Smoothness %
CCW	.08	.15	.04	.18	.027	60
CW	.07	.16	.05	.22	.033	69
CCW	.09	.2	.06	.16	.027	40
CW	.10	.2	.06	.23	.035	55
CCW	.15	.3	.09	.2	.033	20
CW	.15	.3	.09	.4	.060	40
CCW	.45	.9	.27	.25	.033	14
CW	.45	.9	.27	.60	.090	33
CCW	.75	1.6	.47	.3	.045	9.5
CW	.75	1.6	.47	.8	.120	25
CCW	1.05	2.2	.66	.3	.045	6.7%
CW	1.05	2.3	.66	.9	.14	19.5%
CCW	1.5	3.3	1.0	.3	.045	4.5
CW	1.5	3.3	1.0	.8	.12	12
CCW	3.0	6.5	1.9	.3	.045	2.3
CW	3.0	6.5	1.9	.6	.09	4.6
RISE TIME = .5 sec						

TABLE 4.4.1



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Closed Loop Step Response Test

Elevation Axis

Direction of Rotation	Input (Volts)	Average S.S. tach output(Volts)	Average S.S. rate °/sec	Ripple (Volts p-p)	Rate Smoothness °/sec	%
Down	.065	.06	.021	.05	.009	43
Up	.065	.03	.011	.04	.007	66
Down	.10	.09	.031	.08	.014	45
Up	.10	.07	.025	.08	.014	55
Down	.13	.13	.046	.07	.012	26
Up	.13	.10	.035	.09	.016	45
Down	.30	.22	.077	.14	.024	31
Up	.30	.21	.073	.16	.028	38
Down	.65	.6	.21	.3	.052	24
Up	.65	.55	.19	.2	.035	19
Down	1.0	.85	.30	.35	.06	20
Up	1.0	.85	.30	.3	.05	17
Down	1.3	1.2	.42	.4	.07	16
Up	1.3	1.2	.42	.4	.07	16
Down	1.9	1.8	.63	.4	.07	11
Up	1.9	1.8	.63	.4	.07	11
Down	2.6	2.6	.81	.5	.09	9
Up	2.6	2.6	.81	.5	.09	9
Down	3.2	3.2	1.0	.5	.09	8.8
Up	3.2	3.2	1.0	.5	.09	8.8

Rise Time = .6 sec

TABLE 4.4.



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4.5

Joystick Response Test

The Joystick Response Test data is shown in
table 4.5.1 below.

Table 4.5.1

Deflections .001"	Output
0	0 mv
10	.07 mv
20	.44 mv
30	55.4 mv
40	20.5 mv
50	40.5 mv
60	68.5 mv
70	100 mv
80	129 mv
90	169 mv
100	213 mv
120	314 mv
140	440 mv
160	565 mv
180	705 mv
200	840 mv
220	1.0 mv
240	1.12 v
260	1.28 v
280	1.45 v
300	1.63 v
320	1.80 v
340	1.95 v
360	2.10 v
380	2.27 v



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4.6

Position Response Tests

The Position Response Test Data is shown in tables 4.6.1 and 4.6.2. The maximum positioning velocity can be calculated from the saturation voltages of the response test by the relationship:

$$V_{max} = \frac{\text{(Saturation Volts)}}{K_f K_t}$$



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Position Error Voltages

Azimuth Axis

Error (deg)	Output (Volts)	Error (deg)	Output (Volts)
0.0	0.030	0.0	-0.001
0.1	1.531	-0.1	-1.222
0.2	2.154	-0.2	-1.954
0.3	3.089	-0.3	-2.629
0.4	3.132	-0.4	-3.093
0.5	3.724	-0.5	-3.690
0.6	3.940	-0.6	-3.899
0.7	4.234	-0.7	-4.038
0.8	4.432	-0.8	-4.250
0.9	4.452	-0.9	-4.350
1.0	4.633	-1.0	-4.504
1.2	4.820	-1.2	-4.769
1.4	4.975	-1.4	-4.914
1.6	4.990	-1.6	-5.045
1.8	5.030	-1.8	-5.097
2.0	5.059	-2.0	-5.109
2.5	5.190	-2.5	-5.217
3.0	5.509	-3.0	-5.498
3.5	5.990	-3.5	-5.905
4.0	6.959	-4.0	-6.590
4.5	7.194	-6.3	-7.899
5.9	7.359		

TABLE 4.5.1



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Position Error Voltages

Elevation Axis
Elevation Axis

Error (deg)	Output (Volts)	Error (deg)	Output (Volts)
0.0	-0.038	-0.0	0.089
0.1	-9.475	-0.1	2.905
0.2	-10.00	-0.2	9.005
0.3	-10.89	-0.3	10.05
0.4	-11.39	-0.4	10.39
0.5	-11.49	-0.5	10.89
0.6	-11.79	-0.6	11.39
0.7	-12.19	-0.7	11.99
0.8	-12.49	-0.8	12.50
0.9	-12.79	-0.9	12.79
1.0	-12.99	-1.0	12.99
1.2	-13.49	-1.2	13.30
1.4	-13.79	-1.4	13.69
1.6	-14.09	-1.6	13.79
1.8	-14.29	-1.8	14.04
2.0	-14.59	-2.0	14.29
2.5	-16.09	-2.5	15.14
3.0	-18.19	-3.0	16.99
3.6	-20.34	-3.3	17.97

TABLE 4.5.2



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